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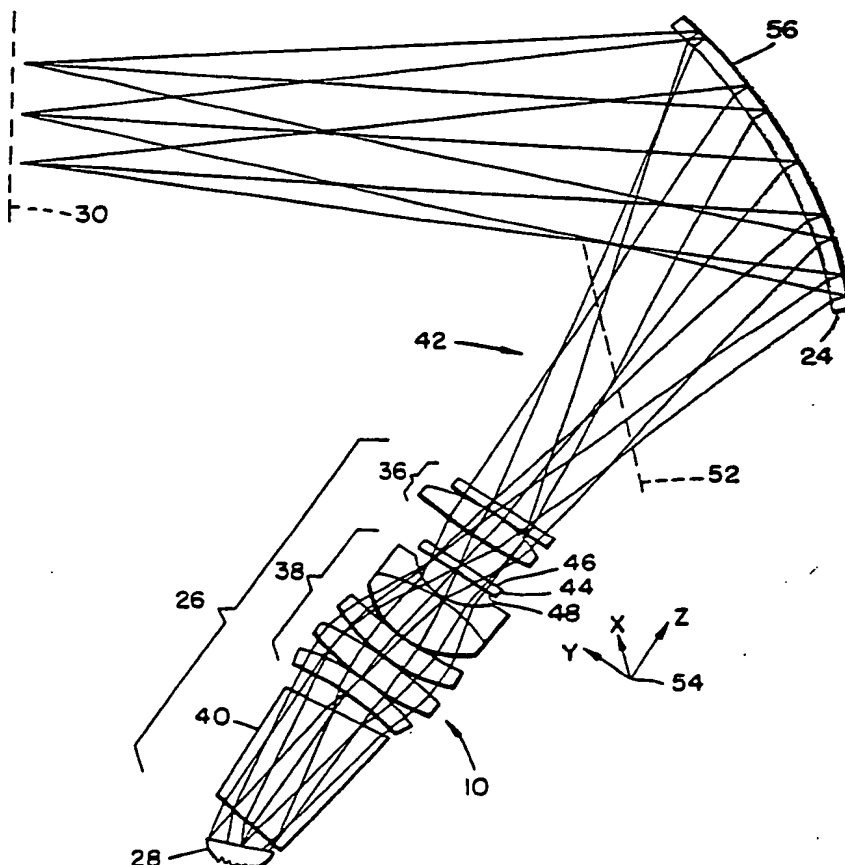
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(54) Title: **COMA-CONTROL PLATE IN RELAY LENS**

(57) Abstract

A head-up display for use in a vehicle is provided with a curved combiner (56) which reflects an image from a cathode ray tube (CRT) (28) as collimated rays to a viewing site. A relay lens (26) is positioned between the CRT (28) and the combiner (56) to magnify and transfer the image. The combiner may be a partially-reflecting mirror or holographic optical element or dielectric laminate. Included within the relay lens is a coma-control plate (44) having two-dimensional undulations described mathematically by a two-dimensional power series having odd symmetry in a plane of a tilting of the combiner and even symmetry in the perpendicular dimension. The coma-control plate (44) substantially reduces coma in an image presented for viewing at infinity, the coma being introduced by the curvature and off-axis use of a surface of the combiner.



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COMA-CONTROL PLATE IN RELAY LENS

1 BACKGROUND OF THE INVENTION

5 This invention relates to relay lenses for head-up optical displays suitable for use in vehicles such as aircraft and, more particularly, to a relay lens having a general aspheric plate with non-rotational symmetry for control of aberrations in images found in a head-up display having a curved reflecting combiner.

10 Head-up displays have a combiner which is at least semitransparent, and is formed of a curved semireflecting plate, or holographic optical element by which an image can be presented superposed upon a scene external to the aircraft, such external scene being of
15 the "real world" as viewed through a window of the aircraft. The combiner presents both the image and the external scene simultaneously to a viewer or operator of a vehicle, the combiner permitting the viewer to see straight ahead to be able to pilot a vehicle.
20 Typically, the display equipment includes a generator of the image, such as a cathode ray tube (CRT) plus a relay lens which focuses and directs optical rays from the CRT to the combiner for presentation to the viewer.

25 A problem arises in that the curvature and off-axis characteristic of the combiner affects the optical

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1 characteristics of an image by introducing aberration,
primarily coma, in the image presented to the viewer.
Attempts have been made to compensate for the
aberration by the inclusion of tilted and decentered
5 elements in the relay lens. However, these attempts
have been disadvantageous in that the resulting
compensation still allowed the presence of excessive
image aberration. Furthermore, the compensation was
obtained at a cost of complexity, difficulty of
10 mounting the lens elements, and difficulty of
alignment.

SUMMARY OF THE INVENTION

15 The aforementioned problem is overcome and other
advantages are provided by a relay lens incorporating a
coma-control plate to reduce the presence of two-
dimensional aberration. In accordance with the
invention, the plate has a planar surface with an
20 opposed surface having two-dimensional undulations
described by a two-dimensional power series, such as a
power series employing Zernike terms.

25 In accordance with a feature of the invention, the
coma-control plate is located within the relay lens at
a reimaged location of the display's exit pupil. This
construction of the relay lens can be accomplished
essentially without enlargement of the physical size of
the relay lens.

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1 BRIEF DESCRIPTION OF THE DRAWING

5 The aforementioned aspects and other features of the invention are explained in the following description, taken in connection with the accompanying drawing wherein:

10 Fig. 1 is a simplified stylized view of an aircraft cockpit carrying a head-up display of the invention;

Fig. 2 is an enlarged view of an optical portion of the system of Fig. 1, shown diagrammatically; and

15 Fig. 3 is a further embodiment of the optical arrangement of Fig. 2 by the inclusion of a folding mirror.

DETAILED DESCRIPTION

20 Fig. 1 shows a head-up display system 10 mounted within a vehicle which, by way of example, is shown as an aircraft 12. The aircraft 12 carries a pilot 14 seated within a seat 16 in front of a console 18. Only a portion of the aircraft 12 is shown for demonstrating
25 implementation of the system 10. Included within Fig. 1 is a window 20 on the side of the aircraft 12 and a window 22 in the front of the aircraft 12, the windows 20 and 22 allowing the pilot 14 to view outside the aircraft 12.

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1 The system 10 includes a combiner 24, a relay lens 26
and a cathode ray tube (CRT) 28. The combiner 24 is
mounted on the console 18 by brackets (not shown) and
positioned between the window 22 and the pilot 14. The
5 relay lens 26 and the CRT 28 are also secured by
brackets (not shown) to the console 18. The lens 26
and the combiner 24 serve to collimate rays of an image
on the CRT 28 through a plane at the face 30 of the
pilot 14. The collimated rays provided by the combiner
10 24 allow the pilot to focus on the CRT image as though
the image were located at infinity. Thereby, the
lenses in the pilot's eyes are set to view, via the
window 22, an external scene located at infinity and,
simultaneously, to view the CRT image which also
15 appears at infinity. The image presented by the CRT 28
is generated with the aid of an electronics unit 32,
shown in phantom within the console 18, the unit 32
being connected via an electrical cable 34 to the CRT
28.

20

The combiner 24 is formed as a partially reflecting
mirror or holographic optical element for presenting
the image of the CRT 28 while being substantially
transparent to radiation propagating through the window
25 22 to the pilot 14. Thereby, the pilot 14 can view a
scene (not shown) external to the aircraft directly
through the combiner 24 and the window 22. Such
viewing of the external scene by the pilot 14 can be
done concurrently with a viewing of an image presented
30 by the CRT 28.

Fig. 2 shows, in diagrammatic form, an enlargement of

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1 the system 10. The face 30 of the pilot 14 is shown by
a dashed line 30 indicating a plane or pupil of
collimated rays from the image displayed by the CRT 28,
only the front portion of the CRT 28 being shown in
5 Fig. 2. The relay lens 26 comprises a small lens group
36, a large lens group 38, and a prism or optical wedge
40. The optical wedge 40 faces the CRT 28, and the
small lens group 36 faces the combiner 24. Rays 42 of
light are shown propagating from the CRT 28 via the
10 relay lens 26 to the combiner 24 from which the rays 42
are directed to the pilot's face 30. The combiner 24
is provided with a slight curvature to facilitate a
collimating of the CRT presentation at the plane of the
pilot's face 30. In a preferred embodiment of the
15 invention, the combiner 24 is curved in two dimensions,
the curvature being about an X axis, perpendicular to
the plane of the sheet of drawing containing Fig. 2,
and about a Y axis which is parallel to the plane of
the drawing. The combiner 24 is advantageously
20 provided with a spherical surface. The combiner 24 is
tilted about the X axis relative to a line of sight
from the pilot's face 30 in accordance with the
location of the relay lens 26 so as to direct rays from
the CRT 28 to the pilot. Aberrations introduced by
25 reflection of the rays 42 from the combiner 24 are
primarily in the nature of coma.

In accordance with the invention, the system 10
includes a coma-control plate 44 inserted within the
30 relay lens 26 between the small lens group 36 and the
large lens group 38. The plate 44 has a front surface
46 which is curved in two dimensions, and a back

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1 surface 48 which is flat. By virtue of the curvature
of the front surface 46, the plate 44 compensates for
abberations in the displayed image introduced by
curvature and off-axis use of the combiner 24.

5

Fig. 3 shows a head-up display system 10A which is an
alternative embodiment of the system 10 of Fig. 2, the
embodiment of Fig.3 being accomplished by the inclusion
of a planar folding mirror 50 in the system 10A to fold
10 the paths of the rays 42. The location of the fold is
indicated by a dashed line 52 in Fig. 2. The system
10A of Fig. 3 includes a relay lens 26A comprising a
small lens group 36A, a large lens group 38A, an
optical wedge 40A and a coma-control plate 44A having a
15 front surface 46A and a back surface 48A. Optical
elements of the lens group 38A are located about a
common axis. The plate 44A is of substantially the
same form as the plate 44, and includes a front surface
46A which is curved in two dimensions, and a back
20 surface 48A which is flat.

Either of the embodiments of Figs. 2 and 3 may be used
for construction of the invention, the choice of the
embodiment depending on the physical constraints of the
25 environment in which the invention is to be situated.
By way of example, in the case of the aircraft 12 of
Fig. 1, if there is space for mounting the CRT 28 in a
vertical position in front of the console 18, as shown,
then the embodiment of Fig. 2 is readily installed. In
30 contrast, in the event that the CRT 28 is to be mounted
within the console 18, then the embodiment of Fig. 3 is
to be installed. The path of propagation of rays of

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1 radiation from the CRT 28 to the pilot's face 30 may be
regarded as being composed of two legs, the first leg
extending from the CRT 28 to the combiner 24 (Fig. 2)
and the second leg extending from the combiner 24 to
5 the pilot's face 30. The first leg may be folded by
the mirror 50 in Fig. 3. While the focal lengths and
other characteristics of the lens elements of the two
embodiments are to be established in accordance with
the geometry of the installation, both embodiments
10 operate in the same fashion as will now be described.

The invention provides a highly precise image in the
head-up display systems 10 and 10A by use of the coma-
control plates 44 and 44A, respectively, which plates
15 have a nonrotationally but bilaterally symmetric, coma-
effecting, aspheric configuration on the respective
front surfaces 46 and 46A. To facilitate the ensuing
description, reference will be made only to the system
10 and the plate 44 of the lens 26, it being understood
20 that the description applies equally well to the system
10A incorporating the plate 44A in the lens 26A.

The plate 44 is situated at the pupil location in the
relay lens 26, and introduces the beneficial effect of
25 reducing or eliminating tilting and decentering of
individual elements of the lens 26, which tilting and
decentering has been required heretofore to compensate
for image aberration introduced by the curvature and
off-axis use of the combiner 24. The introduction of
30 the plate 44 is compatible with the combiner of a head-
up display introducing coma, with or without
astigmatism, across the field of view to compensate for

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1 the coma and to present the image with a high level of
precision.

5 In the design of a head-up display, first-order
properties of the combiner 24 relating to eye relief,
focal length, off-axis angle, and similar
considerations, are generally dictated by the
dimensions of the aircraft cockpit. Within these
10 constraints, one may choose to perform a preliminary
optimization of the image quality by, for example,
correcting a series of differential rays at the
combiner output pupil. This is accomplished by use of
a computer and any one of a number of available optical
15 ray-tracing programs by which the performance of the
optical system can be determined.

In the designing of the optical system with the aid of
a computer ray-tracing program, differential rays may
be presented showing inclination of aberrated rays
20 about a chief ray which is properly focused. By
altering parameters of the optical system, the position
and orientation of these rays can be uniformly
positioned about the field of view to reduce focusing
errors to residual values of less than one milliradian
25 throughout the field of view. As a practical matter,
the focusing errors may be regarded as being
eliminated. In terms of use of the ray-tracing
program, if the combiner 24 is a mirror, the above
process involves the establishment of a local surface
30 normal at all points of the combiner; if the combiner
is a holographic optical element, the foregoing process
involves the establishment of a local grating vector.

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1 Such design techniques are commonly employed in optical design and need not be elaborated herein.

5 The dominant aberration remaining after elimination of focal errors by the above process is coma. Depending on the first-order properties of the optical system, the magnitude of the coma may be in the region of 15 to 30 milliradians. The extent of the coma is substantially constant across the field of view. This
10 ensures proper operation of the combiner with the relay lens in the optical system of the invention.

The plate 44 is located within the relay lens 26 at a site which may be characterized as a reimage site of a
15 pupil located at the pilot's face 30. The reimage site is found by considering a pair of intersecting rays at the face 30, following these rays past the combiner 24 and through the small lens group 36 to the location at which these two rays again intersect. This is the site
20 of the reimaged pupil, and the site at which the plate 44 is to be located. The location and construction of the plate 44 is the same for both mirror and holographic manifestations of the combiner 24. It is noted that the use of a semitransparent mirror for the
25 combiner 24 allows approximately 50% transmission of light from scenes external to the aircraft to the pilot 14 while, in the case of the holographic implementation of the combiner 24, the foregoing transmissivity is increased to approximately 95% per cent. Similarly,
30 for rays emanating from the CRT 28, the semitransparent mirror for the combiner 24 will reflect approximately 50% of the light to the pilot 14, while in the case of

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1 the holographic implementation of the combiner 24, the foregoing reflectance can be increased to approximately 90%.

5 With respect to the emplacement of the plate 44 at the site of the reimaged pupil, it is advantageous to align the plate at the same orientation as the pupil image so that the aspheric front surface 46 can control the coma uniformly at all points in the field of view. It is
10 also noted that, if desired, the aspheric and the planar surfaces of the plate 44 may be interchanged such that the aspheric surface is at the back side of the plate and the planar surfaces at the front side of the plate. However, in the preferred embodiment of the
15 invention, the front surface 46 is provided with the undulations of the aspheric surface while the back surface 48 is planar. While it is possible to construct both of the surfaces 46 and 48 with undulations, adequate control of coma and facility of
20 construction are attained in the preferred embodiment by leaving one of the surfaces planar.

The aspheric properties of the front surface 46 are implemented by forming two dimensional undulations
25 within the front surface 46 by use of well-known lens-forming equipment, such as a diamond stylus which grinds the lens surface under automatic position control in two dimensions.

30 The surface 46 of the plate 44 may be described with reference to a set of coordinate axes 54. The Z axis is perpendicular to the planar surface 48 of the plate

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- 1 44. The X and the Y axes are parallel to the planar
surface 48, the Y axis, as noted above, being parallel
to the sheet of drawing and the X axis, as noted above,
being perpendicular to the sheet of drawing of Fig. 2.
5 The front surface 46 is provided with undulations
described by the following equation

$$Z = K_1 Y (X^2 + Y^2) + K_2 Y (X^2 + Y^2)^2$$

- 10 wherein Z is the amplitude of an undulation as measured
from a reference plane passing through the origin of
the set of coordinate axes 54. K_1 and K_2 are
constants, the values of which are to be selected by an
optical ray-tracing program. This equation may be
15 characterized as a power series containing Zernike
terms of various orders. Additional terms can be
included to compensate for other optical aberrations to
provide for a further optimization of the image
presented to the pilot. However, even with the use of
20 such additional terms (not shown), the dominant effect
of the aspheric plate 44 will be the control of coma.

- In the formation of the combiner 24 as a semi-
reflecting mirror, the combiner 24 is fabricated of
25 glass with a thin layer of silver or aluminum or
several thin layers of dielectric material deposited on
the convex back surface at 56. In the case of
construction of the combiner 24 with a holographic
optical element, the holographic optical element is
30 constructed as a gel deposited along the concave back
surface at 56. A glass cover layer (not shown) may be
placed over the back surface of the gel to protect the

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1 gel. In such case, the combiner 24 is formed as a
laminated comprising a front layer of glass having a
thickness of approximately 1/4 inch, a layer of
5 dichromated gelatin having a thickness of approximately
12 microns, and a back layer of glass which is
approximately 1/8 inch thick. The gelatin serves as a
recording medium for recording an interference pattern
of two beams of light emanating from two coherent point
10 sources, which recorded interference pattern is formed
during the construction of the combiner 24 and provides
the requisite diffraction characteristics for
collimating the rays of light from the CRT display. It
is noted that the holographic optical element is
15 sensitive to wavelength of the light, the optical
characteristics being selected to diffract the
monochrome color of the CRT display, while allowing
light of other colors to pass through the combiner 24
unimpeded. By way of yet a further embodiment, the
gelatin may be replaced with a dielectric material for
20 construction of the combiner as a dielectric laminate.

It is noted that, in the equation, the expression has
even symmetry with respect to the variable X, but odd
symmetry with respect to the variable Y. This is due to
25 the fact that tilting of the combiner 24 is about the X
axis only, there being no tilting about the Y axis,.
As a result, the coma control is accomplished by odd
symmetry in the Y component of the surface 46 while
even symmetry is found in the X component of the
30 surface 46. In the construction of the plate 44, the
thickness thereof is approximately 0.15 inches. The
plate is constructed of glass having a commonly

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1 available refractive index such as 1.52 or 1.79, by way
of example. The values of the constants K_1 and K_2 are
dependent also on the values of the index of refraction
as is well known in the utilization of an optical ray-
5 tracing program for computer-aided design of optical
systems.

The invention is useful with relay lenses of various
configurations. By way of example, as shown in Fig. 2,
10 the large lens group 38 is composed of five elements
comprising three singlets and one doublet that share a
common optical axis. The small lens group 36 has two
elements in Fig. 2 and one element in Fig. 3. The
optical wedge 40 aids in orienting the plane of the
15 face of CRT 28. The physical shape of the wedge 40
differs from the shape of the wedge 40A so as to
provide for the desired bending of rays to orient the
image with the face of the CRT 28 in the respective
configurations of the optical systems of Fig. 2 and
20 Fig. 3.

Implementation of the invention simplifies construction
of a relay lens while retaining flexibility on the
design of a head-up display so as to allow
25 installation of the display subject to constraints of
various physical considerations such as the limited
confines of an aircraft cockpit.

It is to be understood that the above described
30 embodiments of the invention are illustrative only, and
that modifications thereof may occur to those skilled
in the art. Accordingly, this invention is not to be

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- 1 regarded as limited to the embodiment disclosed herein, but is to be limited only as defined by the appended claims.

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CLAIMS

What is claimed is:

- 1 1. A relay lens for use in a display system wherein imaging rays are reflected from a curved surface of a combiner, the relay lens comprising:
 - 5 a first lens group having at least one optical element and a second lens group having at least one optical element, each of said lens groups being disposed along a direction of propagation of rays
 - 10 of radiation carrying image data to be presented as collimated rays at a viewing site by said system, said rays of radiation propagating along a path comprising a first leg and a second leg
 - 15 wherein said first leg extends through said relay lens, and wherein radiation propagates along said first leg to reflect off said curved surface of said combiner via said second leg to reach
 - 20 said viewing site, there being a reimaging location on said first leg alongside an element of said relay lens for reimaging a pupil of collimated rays situate on said second leg at said
 - 25 viewing site; and
 - a coma-control plate disposed on said first leg at said reimaging location for

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30 removing aberration introduced by said
curved surface of said combiner, said
plate having first and second opposed
surfaces, at least one of said opposed
surfaces being configured with
35 undulations described mathematically by
a power series in two orthogonal
dimensions.

1 2. A relay lens according to Claim 1 wherein
the surface of said combiner is spherical and is tilted
in one plane about an axis perpendicular to said plane,
and wherein the undulations of said first surface of
5 said plate have even symmetry in a dimension parallel
to the axis of tilting of said combiner, the
undulations having odd symmetry in a dimension
perpendicular to said axis of tilting.

1 3. A relay lens according to Claim 2 wherein
the undulations of the first surface of said plate are
described mathematically by

5
$$Z = K_1 Y (X^2 + Y^2) + K_2 Y (X^2 + Y^2)^2$$

wherein X is a dimension parallel to
said axis of tilt of said combiner and Y
is a dimension perpendicular to the X
10 dimension, and wherein K₁ and K₂ are
constants, Z being the amplitude of
undulation.

1 4. A relay lens according to Claim 3 wherein

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said reimaging location is situated between said first lens group and said second lens group.

1 5. A display system wherein imaging rays are transmitted from an image source to a viewing site by redirection from a curved surface of a combiner, the system comprising:

5 an image source;

10 a combiner having a curved surface for collimating the rays at the viewing site; and

15 a relay lens including a first lens group having at least one optical element and a second lens group having at least one optical element, each of said lens groups being disposed along a direction of propagation of rays of radiation carrying image data to be displayed at a viewing site by said system, said rays of radiation propagating along a path comprising a first leg and a second leg wherein said first leg extends through said relay lens, and radiation propagates along said first leg to reflect off said curved surface of said combiner via said second leg to reach said viewing site, there being a reimaging location between said first lens group and said

20

25

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30 second lens group for reimagining a pupil
of rays of said second leg at said
viewing site; and wherein

35 a coma-control plate disposed on said
first leg at said reimagining location for
controlling coma introduced by said
curved surface of said combiner, said
plate having first and second opposed
40 surfaces, said first surface being
configured with undulations described
mathematically by a power series in two
orthogonal dimensions, said second
surface being planar.

1 6. A display system according to Claim 5
wherein said combiner comprises a half-silvered mirror.

1 7. A display system according to Claim 5
wherein said combiner comprises a dielectric coating
laminate.

1 8. A display system according to Claim 5
wherein said combiner comprises a holographic optical
element.

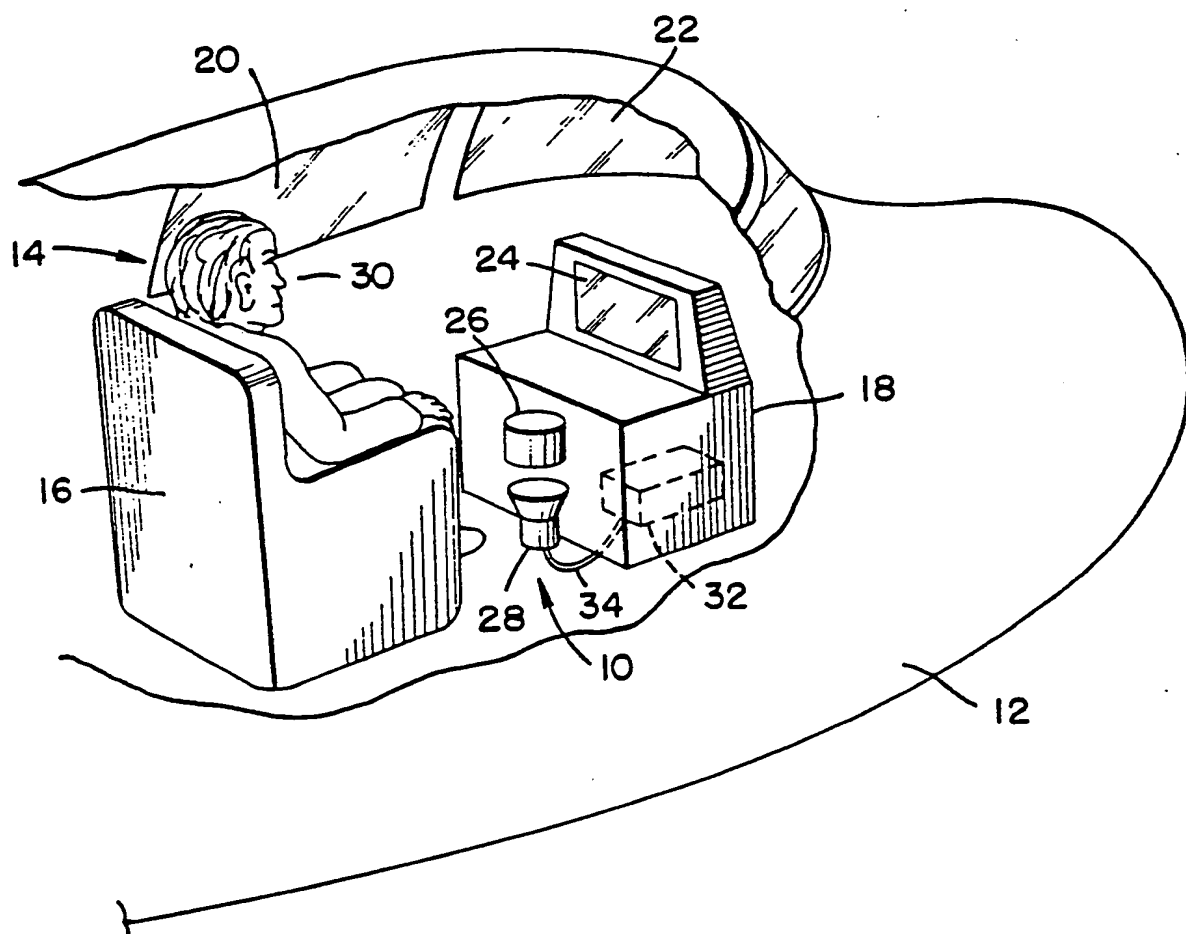
1 9. A display system according to Claim 5
further comprising a folding mirror disposed between
said relay lens and said combiner, said first leg of
said propagation path being folded about said folding
5 mirror to provide a predetermined overall configuration
to said system.

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- 1 10. A display system according to Claim 9
 wherein said system is a head-up display, and said
 image source is a cathode ray tube, said relay lens
 further comprising an optical wedge for orienting an
5 image produced by said image source to be in alignment
 with a plane of said viewing site.

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FIG. 1.



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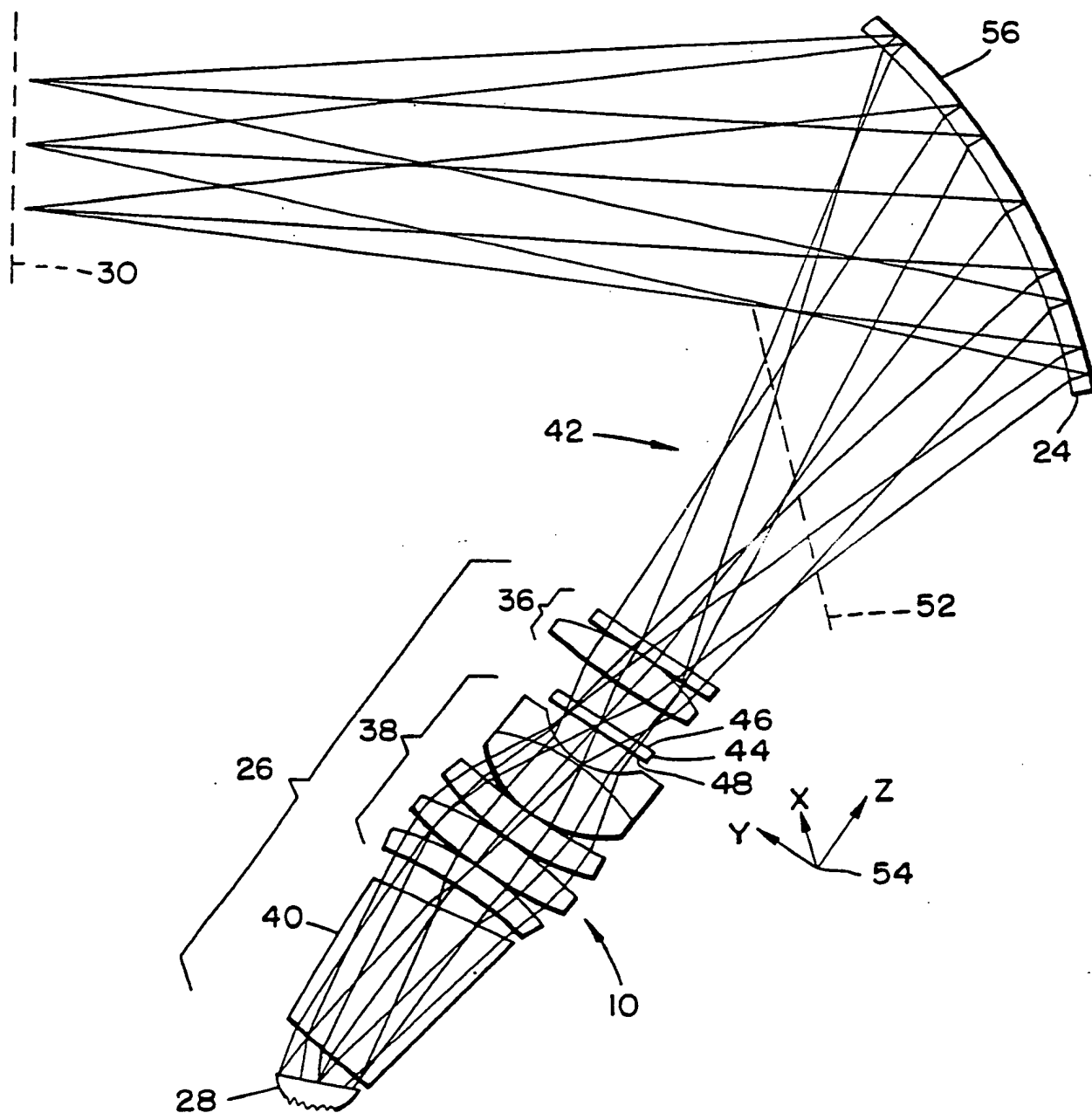
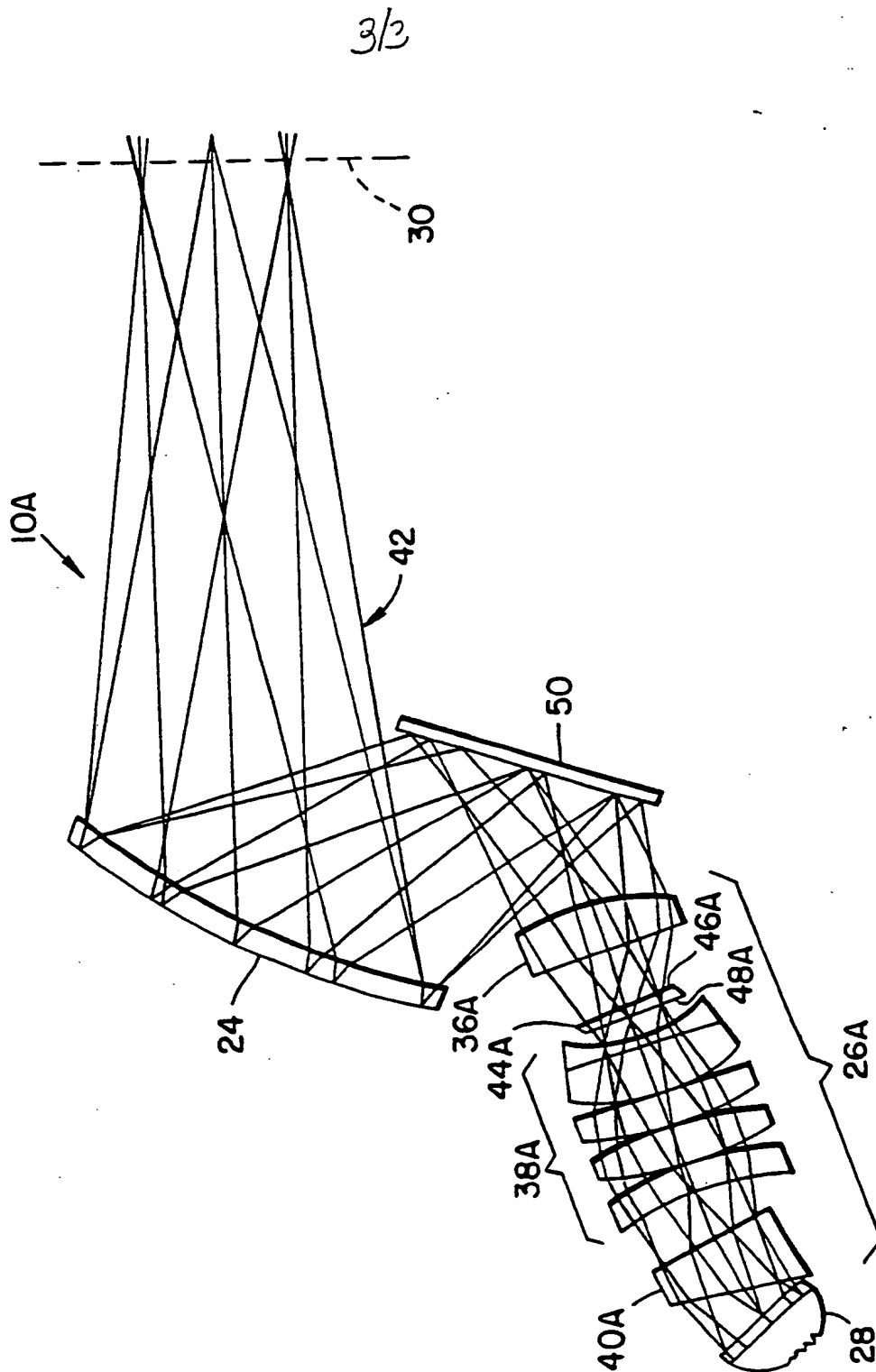
FIG. 2.

FIG. 3.



INTERNATIONAL SEARCH REPORT

PCT/US 87/03099

International Application No

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all) * According to International Patent Classification (IPC) or to both National Classification and IPC IPC ⁴ : G 02 B 27/00																	
II. FIELDS SEARCHED <div style="text-align: right; font-size: small;">Minimum Documentation Searched *</div> <table style="width: 100%; border: none;"> <tr> <td style="width: 25%; border: none; vertical-align: top;"> <div style="border: 1px solid black; padding: 5px; margin-bottom: 5px;"> Classification System </div> <div style="border: 1px solid black; padding: 5px;"> IPC⁴ </div> </td> <td style="width: 75%; border: none; vertical-align: top;"> <div style="border: 1px solid black; padding: 5px; margin-bottom: 5px;"> Classification Symbols </div> <div style="border: 1px solid black; padding: 5px;"> G 02 B </div> </td> </tr> </table> <div style="text-align: center; font-size: x-small; margin-top: 5px;"> Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched * </div>			<div style="border: 1px solid black; padding: 5px; margin-bottom: 5px;"> Classification System </div> <div style="border: 1px solid black; padding: 5px;"> IPC⁴ </div>	<div style="border: 1px solid black; padding: 5px; margin-bottom: 5px;"> Classification Symbols </div> <div style="border: 1px solid black; padding: 5px;"> G 02 B </div>													
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III. DOCUMENTS CONSIDERED TO BE RELEVANT * <table style="width: 100%; border: none;"> <tr> <th style="width: 10%; border: none; font-size: x-small;">Category *</th> <th style="width: 70%; border: none; font-size: x-small;">Citation of Document, ** with indication, where appropriate, of the relevant passages **</th> <th style="width: 20%; border: none; font-size: x-small;">Relevant to Claim No. **</th> </tr> <tr> <td style="border: none; text-align: center; vertical-align: top;">X</td> <td style="border: none; vertical-align: top;"> EP, A, 0151455 (FLIGHT DYNAMICS INC.) 14 August 1985, see figures 1-4; abstract; page 4, lines 21-27; page 5, lines 2-10, 29, 30; page 6, lines 5-9; page 7, lines 4-12; page 11, lines 6-11; page 12, lines 4-11; page 13, lines 8-11; page 14, lines 1-4 -- </td> <td style="border: none; text-align: center; vertical-align: top;">1-3, 5-8, 10</td> </tr> <tr> <td style="border: none; text-align: center; vertical-align: top;">Y</td> <td style="border: none; vertical-align: top;"> EP, A, 0007039 (HUGHES AIRCRAFT CO.) 23 January 1980, see figure 1; abstract -- </td> <td style="border: none; text-align: center; vertical-align: top;">1, 5, 9, 10</td> </tr> <tr> <td style="border: none; text-align: center; vertical-align: top;">Y</td> <td style="border: none; vertical-align: top;"> Optical Spectra, March/April 1968, no. 2, J.J. Villa: "Catadioptric lenses", part 1, pages 57-63, see figures 10-12B; abstract; page 61, left-hand column, lines 27-29; right-hand column, lines 1-14, 20-23 -- </td> <td style="border: none; text-align: center; vertical-align: top;">1, 5, 9, 10</td> </tr> <tr> <td style="border: none; text-align: center; vertical-align: top;">A</td> <td style="border: none; vertical-align: top;"> US, A, 3589796 (C.F. SCHAEFER) 29 June 1971, see figure 2; abstract; column 2, lines 47-49 ----- </td> <td style="border: none; text-align: center; vertical-align: top;">1, 6</td> </tr> </table>			Category *	Citation of Document, ** with indication, where appropriate, of the relevant passages **	Relevant to Claim No. **	X	EP, A, 0151455 (FLIGHT DYNAMICS INC.) 14 August 1985, see figures 1-4; abstract; page 4, lines 21-27; page 5, lines 2-10, 29, 30; page 6, lines 5-9; page 7, lines 4-12; page 11, lines 6-11; page 12, lines 4-11; page 13, lines 8-11; page 14, lines 1-4 --	1-3, 5-8, 10	Y	EP, A, 0007039 (HUGHES AIRCRAFT CO.) 23 January 1980, see figure 1; abstract --	1, 5, 9, 10	Y	Optical Spectra, March/April 1968, no. 2, J.J. Villa: "Catadioptric lenses", part 1, pages 57-63, see figures 10-12B; abstract; page 61, left-hand column, lines 27-29; right-hand column, lines 1-14, 20-23 --	1, 5, 9, 10	A	US, A, 3589796 (C.F. SCHAEFER) 29 June 1971, see figure 2; abstract; column 2, lines 47-49 -----	1, 6
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<div style="display: flex; justify-content: space-between; font-size: x-small;"> <div style="width: 45%;"> <p>* Special categories of cited documents: 10</p> <p>"A" document defining the general state of the art which is not considered to be of particular relevance</p> <p>"E" earlier document but published on or after the international filing date</p> <p>"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)</p> <p>"O" document referring to an oral disclosure, use, exhibition or other means</p> <p>"P" document published prior to the international filing date but later than the priority date claimed</p> </div> <div style="width: 45%;"> <p>"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention</p> <p>"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step</p> <p>"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art</p> <p>"Δ" document member of the same patent family</p> </div> </div>																	
IV. CERTIFICATION <table style="width: 100%; border: none;"> <tr> <td style="width: 50%; border: none; vertical-align: top;"> Date of the Actual Completion of the International Search 13th June 1988 </td> <td style="width: 50%; border: none; vertical-align: top;"> Date of Mailing of this International Search Report <div style="font-size: 1.5em; font-weight: bold;">11 JUL 1988</div> </td> </tr> <tr> <td style="border: none; vertical-align: top;"> International Searching Authority <div style="text-align: center; font-weight: bold;">EUROPEAN PATENT OFFICE</div> </td> <td style="border: none; vertical-align: top;"> <div style="text-align: center;"> Signature of Authorised Officer <div style="font-weight: bold; margin-top: 5px;">P.C.G. VAN DER PUTTEN</div> </div> </td> </tr> </table>			Date of the Actual Completion of the International Search 13th June 1988	Date of Mailing of this International Search Report <div style="font-size: 1.5em; font-weight: bold;">11 JUL 1988</div>	International Searching Authority <div style="text-align: center; font-weight: bold;">EUROPEAN PATENT OFFICE</div>	<div style="text-align: center;"> Signature of Authorised Officer <div style="font-weight: bold; margin-top: 5px;">P.C.G. VAN DER PUTTEN</div> </div>											
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ANNEX TO THE INTERNATIONAL SEARCH REPORT ON INTERNATIONAL PATENT APPLICATION NO.

US 8703099

SA 21364

This annex lists the patent family members relating to the patent documents cited in the above-mentioned international search report. The members are as contained in the European Patent Office EDP file on 28/06/88. The European Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
EP-A- 0151455	14-08-85	JP-A- 60198515 US-A- 4669810	08-10-85 02-06-87
EP-A- 0007039	23-01-80	US-A- 4218111	19-08-80
US-A- 3589796	29-06-71	GB-A- 1156578	02-07-69

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